

Design and implementation of the [®]SELECTRIC System/2000

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This paper presents an overview of the papers in this issue of the *IBM Journal of Research and Development* covering the design and implementation of the [®]SELECTRIC System/2000 Typewriter/Printer products. The SELECTRIC System/2000 products comprise a nonimpact typewriter and printer, two impact typewriters, and an impact printer which use printwheel technology. The development approach for the SELECTRIC System/2000 products, which included design for automation, introduction of new technologies, and product development concurrent with manufacturing, was accomplished by the use of common architecture, hardware, and software.

Introduction

The IBM [®]SELECTRIC System/2000 Typewriter/Printer products bring to the office environment an entirely new technology as well as major improvements to an existing one. The first, resistive ribbon nonimpact printing, was researched, developed, and refined by three IBM laboratories at Yorktown Heights, New York, San Jose, California, and

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Lexington, Kentucky. The second, printwheel impact printing, had been employed commercially for a decade but was the object of significant improvement. Instead of choosing between impact and nonimpact technologies, both were employed to meet diverse application requirements. For example, whereas both printing technologies can deliver correspondence-quality printing, impact printing alone can meet the need for multiple carbon copies, but nonimpact printing provides quieter operation as well as higher speed and greater graphic capability.

A "family" of products evolved from this dual choice: two impact typewriters, a nonimpact typewriter, an impact printer, and a nonimpact printer. These products offer correspondence-quality printing by machines that can stand alone, are interactive with other systems, and are enhanced by the addition of special features. Although the products retain the name SELECTRIC, the familiar spherical printing element is gone, replaced by printwheel and resistive ribbon technologies. On the other hand, the SELECTRIC System/2000 retains and improves upon the concepts of addable features/functions, selection from a wide range of interchangeable fonts, and traditional standards of excellence in reliability and usability.

Incorporated within the SELECTRIC System/2000 are technological advances, innovative features, refinement of previously available functions, and because of the emphasis on usability, novel solutions to user problems. For instance, in the resistive ribbon products, the ribbon that is used for printing is also used for correction. Further, all products employ multiple-step motors in a machine architecture that

eliminates complex mechanical hardware. Platen knobs used for paper positioning have been supplanted by microindexing controls located on the keyboard. The innovative Spell Check Option provides real-time feedback to the operator, signaling misspelled words as they are being typed.

A design objective to provide competitive price coupled with high function in the SELECTRIC System/2000 was achieved through the use of common architecture, hardware, and software. This design was supported by significant advances in production/manufacturing/automation techniques.

This paper presents an overview of these accomplishments, which are elaborated further in succeeding papers.

Overview

• Resistive ribbon technology

The nonimpact printer and correcting typewriter of the SELECTRIC System/2000 represent the first commercial application of a resistive ribbon thermal transfer technology. Historically, thermal transfer printing has evolved from 1) utilization of heat-sensitive papers that achieved less than letter print quality at considerable cost; 2) a more recent application of a thermal printhead with a heat-sensitive ribbon, permitting the use of plain paper but having limitations in terms of print resolution, paper choice, print speed, and hardware complexity of the printhead.

One alternative means of achieving thermal ink transfer is to incorporate electrical resistance elements into the body of the ribbon itself. Shih and Dove [1] discuss the electrical conduction processes within the ribbon and include a model describing electrical behavior. Electrodes are used to inject electrical current into the ribbon; the resultant direct heating is sufficiently intense to melt the ink, transferring it to plain paper. Advantages of this approach are higher printing speed and high resolution, as well as erase capability, unique among nonimpact printers. Direct heating of the ribbon with highly conductive electrodes reduces the print speed restrictions inherent in conventional thermal transfer printing. Pennington and Crooks [2] describe the fundamentals of resistive ribbon thermal transfer technology, including the ribbon and printhead structures; they also discuss the origins of the technology. Mitchell and Pennington [3] were the first to recognize the potential of this new print technology and initiated the early research in IBM. Twardeck [4] describes the electrical and thermal characteristics of IBM's particular implementation of the resistive ribbon thermal transfer print process. Key elements of the current flow path are individually identified and electrically characterized in a way that is relevant to the printing process. Twardeck [4] also explains why higher resolution can be achieved by using this technology.

Laff and Makowka [5] provide a quantitative description of the heating and cooling of resistive ribbon during printing. Computer simulation using finite element methods was used to give a more detailed description of the processes.

Chieu and Sahni [6] report on an experimental technique for measuring ink temperatures by using an infrared radiometric microscope to observe the temperature of ink deposited by the resistive ribbon process on transparent substrates. The peak ink temperatures were observed to depend linearly on input current and inversely on an approximately linear function of writing speed ranging from 2 to 8 inches per second.

Applegate et al. [7] and Bohnhoff et al. [8] supplement this information with a discussion of the printing and correcting characteristics of the resistive ribbon thermal transfer technology.

Printing

The discussion of the printing process includes a description of the printhead, the print cycle, and the timing of the various components necessary for printing. The printhead comprises a vertical array of 40 electrodes equally spaced on 0.106-mm (0.004167-in.) centers. Materials in the printhead were selected to provide temperature resistance, wear resistance, and mechanical compliance. Compliance causes electrical contact between the printhead and the ribbon and provides uniform pressure between the ribbon and paper. A 45° angle between the printhead and the platen also improves compliance; however, this angle complicates the geometry between the printhead and the round platen [7]. In order to print a vertical line on the paper, a compound curvature of the electrodes is required.

Formation of the printing image is controlled by the motion of the printhead, current supplied to the electrodes, and peeling of the ribbon from the paper. Ribbon and printhead are mounted on and transported by a carrier. Printhead velocity must be well controlled during a print or erase operation because this parameter, along with the electrode current, determines the energy density within the ribbon and, consequently, the temperatures generated within the ribbon. The velocity of the carrier is controlled by using a closed-loop servo consisting of a dc motor with an optical encoder for velocity and position feedback [8]. The dc motor drive selected provides flexibility in generating the complex velocity profiles required for the interactive print and erase cycles. The velocity profiles evolved into a 13-to-1 speed range (3.8–50 cm/s) requiring several velocity changes within the cycle. Print velocity affects not only the electrode input energy density but also the imaging characteristics of the resistive ribbon. Print quality increases with print speed up to a range of 7.5–12 cm/s; however, the cost of power and control electronics also increases with print speed. A print rate of 10.16 cm/s (40 characters per second at 10 pitch) was chosen as the optimal operating point.

Ribbon tension is required on the supply side of the printhead to ensure proper ribbon tracking and to peel the ribbon from the page during the print cycle. Since the printhead is spring-loaded against the platen, there is an upper limit on ribbon tension to ensure that the printhead is not pulled from the paper. The tension developed between the printhead and pinch rollers varies with changes in supply-side tension, printhead force, ribbon-metering rate, and friction coefficients at the printhead-to-ribbon and ribbon-to-paper interfaces. With these considerations, the tension must be great enough to provide a force sufficient to peel the ribbon from the page immediately after passage of the printhead. The angle at which the ribbon is peeled from the paper is also important and is a compromise between large and small angles. The 30° angle implemented is large enough to ensure that the ribbon is peeled from the page before the ink is cool but not so large as to cause ribbon tension to pull the printhead away from the platen [7].

Applegate et al. [7] also found that SELECTRIC System/2000 resistive ribbons produce quality printing on papers much rougher than those used by thermal transfer printers. The increased tolerance of the SELECTRIC System/2000 for rough paper is a result of the compliance of the resistive ribbon printhead that improves ink-to-paper contact and the sheet strength of the ink.

Correcting

Print correction, while a proven advantage in typewriter application, has not previously been feasible in nonimpact typewriters. Applegate et al. [7] describe the first implementation of the correcting resistive ribbon technology to reach the marketplace.

Originally, the ability to correct typed copy was demonstrated by restriking the character to be corrected over the previously printed character. This required precise realignment, a special correction ribbon, and the necessity of remembering the character to be corrected. In the present implementation, an unused section of ribbon is positioned over the image to be corrected and the printhead is swept over the ribbon as if to print a block image over the character to be corrected. During the correction process, all forty electrodes in the printhead are turned on at a reduced energy level for the entire character matrix of the character to be corrected. This block technique heats the ink to a temperature at which it bonds permanently to the preprinted character to be corrected but not to the surrounding paper surface. The strength of this bond is a function of the way in which both the electrical energy and the mechanical force of the printhead against the platen are controlled. Ribbon motion is also controlled as in the print cycle, except that a correction roller is introduced to create cooling delay time prior to peeling. The roller also forces a condition of zero relative motion between the ribbon and paper during the bonding and cooling process. This permits formation of a

bond between the ribbon and the image to be corrected before peeling occurs. One advantage of the block correction technique is character correction with a single pattern. After a correction is made, the paper shows no visible evidence of prior printing. Applegate et al. [7] detail the processes involved in resistive ribbon correction and discuss factors such as cooling delay time and double correction.

● *Printer*

Typewriter application requirements (except for correction) governed most of the design decisions for the IBM® QUIETWRITER Printer. Price/performance goals for the printer were achieved through high commonality with the typewriter. In keeping with the philosophy of expandability, this member of SELECTRIC System/2000 was designed to provide low-cost, high-quality output printing when attached to small business systems and personal computers. Design innovations for the printer, therefore, concentrated on user control features, options, and simplicity of use.

Pluggable character font

The nonimpact resistive ribbon typewriter created the need for an electronic character font module analogous to the SELECTRIC Typewriter print element. The font had to be easily changeable, readily accessible, reliable, and universal enough to support current and future requirements. The design of the font module is implemented in a 16K-byte custom ROS array with the architecture supporting expansion to 64K bytes. The character shape data are stored in compressed form using a run-length encoding algorithm optimized around a dot matrix character box. This algorithm is easily implemented in software or hardware and provides efficient compression over a wide range of character shapes. The module, accessed over a serial bidirectional bus, allows random access to the array on any byte boundary. This protocol provides high efficiency for block data transfers and allows the transmission rate to be controlled by either the font module or the host machine. The control tables contained in the array allow the host machine to easily accommodate future keyboard and type style requirements without affecting machine software [8].

Temperature and humidity control

The resistive ribbon technology, a thermal process, is affected by environmental temperatures; however, it has been found [4] that humidity is a greater factor than temperature. Due to the hygroscopic nature of the ink, absorption of moisture from the air changes the mechanical properties of the ink, resulting in larger images because more ink is transferred to the paper. Since environmental conditions differ from office to office, compensation for both humidity and temperature was accomplished with the introduction of an operator control. This control, a multiple-position switch, shifts the print current by small increments.

At high temperature and humidity levels, the operator control switch can be set for a lower value to reduce character boldness. Conversely, for lighter print caused by low temperature or humidity, higher switch positions may be used. A test pattern is provided within the machine to aid the operator in selecting the required settings.

Acoustics

Acoustical feedback to the operator of a key-to-print typewriter is an important human factor. Noise levels that are too high or not synchronous with keyboard entry can interfere with the typing rhythm of the operator and can increase the number of typing errors and decrease typing rate. Controlling the noise levels generated by the movement of the printhead was a major design consideration. The asynchronous sounds generated by the printhead movement were loud enough in the early prototype models to cause some interference with typing productivity. Gear noise, also a dominant factor, was directly proportional to motor speed for a fixed gear ratio. An adaptive velocity control algorithm reduced the noise level by 4 dBA (decibels adjusted to reference level). This lowered the level of noise generated by movement of the printhead below that of the keyboard and eliminated the problem of printhead actuator noise interfering with the typing rhythm of the operator [8]. The total acoustic level achieved by the IBM QUIETWRITER Typewriter is <55 dBA, permitting placement of the typewriter at the point of need without creating noise problems, even in large groupings of machines.

Print flexibility

Print flexibility was a major consideration in the development of the resistive ribbon typewriter. Two pluggable cartridges—each a 220-character font module—are standard equipment in the QUIETWRITER Typewriter. An expanded character set includes non-English alphabets and symbols. This expanded print capability allows an operator to access two standard and two expanded type styles without interrupting keyboarding or playout for special character use. A caps lock which activates uppercase alpha characters, lowercase numerals, and punctuation obviates constant shift-lock switching. Print line visibility (unique in nonimpact typewriter/printers) permits viewing of characters during typing. Four pitches—character sizes and spaces—are designed into the IBM QUIETWRITER Typewriter, printing in 10, 12, 15, and proportional pitch. Typists may also print superscripts and subscripts with automatic return to the original writing line.

The IBM QUIETWRITER Printer can be attached to small business systems and personal computers. When attached to a computer, the printer is capable of variable line feed and double-width print, and can set up to 64 vertical and 28 horizontal tab stops. A special feature port allows for a pinwheel forms feeder for single-part continuous forms.

Printwheel technology

Mayo [9] describes the design criteria and the choice of mechanisms for the [®]WHEELWRITER Typewriters based on recent innovations in automation. In his studies of the effects of automation on design and, conversely, the effect of design on automation, Schaefer [10] found that indirectly through automation, design can significantly enhance product quality. The key to good product design is simplicity. Simple designs have specific characteristics—fewer parts, fewer adjustments, modularity, and a minimal number of part assembly directions. He concludes that products must be designed for automation, not only because they will cost less to manufacture but also because the simpler automatable design makes maximum use of electronics for control functions and is vastly more reliable. Mayo [9] discusses the decisions that led to the final choice of five open-loop stepper motors for the critically required typewriter functions. One each is used for escapement, paper feed, and selection, and two for the ribbon.

The ribbon system tasks were divided between two motors to decrease the complexity of the mechanical hardware and to maintain power requirements consistent with the size of the motors and drivers chosen. In addition to the motors, there is a solenoid that activates a hammer to drive the characters against the platen. Rather than traditionally choosing one motor to do several jobs, the motor tasks were divided to give each the responsibility for one particular task. Each system is designed to be nearly independent of the others. With minimal interaction between systems, design changes in one part of the machine do not cascade into changes in other areas, leading to simpler assembly and repair procedures for the whole machine. When more function is required for one particular part of the machine for a future application, only that one portion need be redesigned. The most compelling reason behind this type of mechanical architecture is the elimination of complex mechanical hardware [9].

Covington et al. [11] present an adhesive formulation and manufacturing technique for the error-correcting tape used in the WHEELWRITER Typewriter. The formulation presented is unique in that it does not employ solvents but is radiation-cured.

Printing

The printwheel cartridge of the WHEELWRITER Typewriters was designed to protect the printing element and to contain the multiple-pitch control and impression force information. The printing cartridge of the WHEELWRITER Typewriters can be changed without removing the ribbon. Conversely, the printing and correcting ribbons, housed in two snap-on cartridges, may each be removed or changed without removing the printwheel cartridge.

Both WHEELWRITER Typewriters have half-index printing capability, allowing superscripts and subscripts to be

produced with an automatic return to the original writing line.

- *Commonality—SELECTRIC System/2000 products*

Hardware

Common to the SELECTRIC System/2000 products is the keyboard assembly, which has a snap-on top cover, with the metal base plate serving as the bottom cover. The keyboard itself, which is common to all the typewriter products, is adjustable to three different angles, allowing the user to set the typing angle.

Covers for the four machines comprise a unified design made of an injection-molded plastic, designed without the conventional platen knobs. Paper handling, loading, and positioning are simpler than with the hand-turned platen knobs. Microindexing control of the platen from the keyboard permits movement of the paper up and down in small increments of 0.026 mm (0.010 in.), allowing accurate repositioning of the writing line and paper ejection without operator manipulation.

The frame, paper feed, and transport assembly (FPT), which includes the paper-handling mechanism, the escapement motor, and the hardware providing support for the rest of the print mechanism, is the same for all machines of the SELECTRIC System/2000.

Software

The two WHEELWRITER machines have almost identical printer control microcode. The QUIETWRITER Typewriter and the WHEELWRITER Typewriter also share their functional software. An important aspect of the software is the way in which the various machines deal with the languages of countries that do not use the English alphabet or have a different set of symbols from those used in the United States. In the QUIETWRITER Typewriter, all of the font data and the keyboard translator are contained in the font module. For each of the typewriters there are more than forty different keyboards available, with each key location having an associated upper-and-lower-case petal position. The WHEELWRITER Typewriters have read-only memory (ROM) to store data used for the multilingual keyboard. A microprocessor is used to interpret the associated petal position. Mayo [9] discusses the use of the Intel 8051 microprocessor in the printwheel typewriters and the choice of basic architecture to accommodate the multilingual capability of the machines. There are no mechanically latched buttons in the keyboard; all latch functions are obtained electronically with a light-emitting diode (LED) assembly snapped into the top keyboard cover.

Keyboards

S. F. DeFosse et al. [12] describe the materials and processing aspects of the membrane switch technology and

design for a low-force membrane switch-type full-travel tactile keyboard. This paper discusses the adaptation of membrane switch technology to a high-reliability keyboard product design, and the interaction of design, materials, and processing variables as revealed through statistical parameter modeling and environmental exposure studies. The authors also outline the design approaches taken and the early rejection of keyboards with membranes that were neither full-travel nor tactile. They detail the keyboard configurations, membrane layout, actuator design, and contact forces and provide insights into failure modes, offering interesting configuration solutions to membrane design problems.

Optional features

The early promise to provide solutions to user problems is evident in two optional features: the Display and the Spell Check Option. Both of these technologies have existed in the marketplace for some time, but neither as used in the IBM SELECTRIC System/2000.

The 24-character liquid crystal display is mobile; that is, it is typist-positionable and movable, with tilt and contrast control. The Display allows the user to see the keystrokes during the "blind typing" aspects of centering and decimal tab. Characters are displayed in three modes: keying to print, line print on carrier return, and no print (display only).

The significance of the SELECTRIC System/2000 Spell Check Option is that checking is done interactively instead of via the "batch" system. Instead of waiting until the end of the document to make corrections and then replaying the corrected information, the system alerts the typist to spelling errors immediately. The Spell Check Option has access to the equivalent of approximately 50 000 English words representing 11 000 root words commonly used in business. Such dictionaries are also available in several other languages. The internal dictionary is augmented by a 300-word supplemental dictionary of proper names, or special vocabulary words that are not in the main dictionary but appear in particular applications. Supplemental words can be added and deleted as needed. The supplemental dictionary is stored in a random access memory (RAM) with battery backup power to prevent loss of the material in case of main power failure.

Summary

A review of the papers in this issue describing the design, development, and production of the SELECTRIC System/2000 family of products leads to the conclusion that the original intent—to develop a synergistic family of products—was eminently achieved. These products offer correspondence quality at a reasonable price, with a choice of machines that stand alone and are expandable.

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Received October 8, 1984; revised April 8, 1985

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